Elasticities of Demand for Gasoline in Canada and the United States

by

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Abstract

Fluctuations in the world price of oil, the concern with greenhouse gas emissions and the efforts to revive the 1997 Kyoto Protocol have resulted in renewed interest in the estimation of elasticities of demand for gasoline.

In this paper, a complete system of demand equations is estimated, including an equation for the demand for gasoline. Canadian Family Expenditure (FAMEX) and United States Consumer Expenditure (CEX) Survey data are used.

Household-level data permits estimation of elasticities for various household groups. Also, differences in demand responsiveness to own-price and income changes are estimated for different regions in Canada and the United States.

Demand is found to be own-price and income inelastic, on the whole, as reported in earlier studies. There is also variation in these elasticities across regions of Canada and the United States. However, larger differences are observed with respect to household size and housing tenure, than to region of residence.

JEL Codes: C3,D1

Keywords:

elasticities; gasoline demand.

1 Introduction

There has always been a significant amount of interest in the estimation of demand models for gasoline. These studies have often focused on demand estimation as a means of obtaining estimates of own-price and income elasticities of demand for gasoline. Dahl and Sterner (1991) recently surveyed this extensive literature. After they stratified studies by data and model type, results indicated a fairly significant degree of consensus with respect to short and long-run own-price and income elasticities. While reporting short and long-run own-price elasticities of -0.26 and -0.86, on average, they also concluded that there was strong evidence that the long-run income elasticity of demand was greater than one, whereas the short-run income elasticity was less than one. This finding with respect to long-run income elasticity they viewed as a cause for concern, particularly in the United States, since they predicted increased demand for gasoline with continued income growth.

More recently, Schmalensee and Stoker (1999) provided evidence that high long-run income elasticities could be due to a failure to control for numbers of drivers in households. On this basis, Schmalensee and Stoker (1999) concluded that the income elasticities which have appeared in the literature, particularly when based on cross-sectional data, were 50% higher than they would be if one controlled for the number of licensed drivers. They then concluded that future growth in demand would likely be lower than had previously been predicted. Yatchew and No (2001), using similar methodology, but with a microdata set containing more detailed price and household characteristics information, provided evidence which were consistent with the results of Schmalensee and Stoker (1999).

Recent fluctations in the world price of oil have led to renewed interest in estimation of elasticities of demand for gasoline. Also, the difficulties encountered in moving ahead with commitments under the Kyoto Protocol of 1997 to reduce greenhouse gas emissions by approximaely 5% from their 1990 levels over the next decade have led to a re-consideration of the responsiveness of fuel consumption to changes in price. A subsequent agreement in November, 2001 for implementation of the U.N. treaty resulting from the Kyoto Protocol places emphasis on the creation of carbon "sinks", and emissions trading.

Notwithstanding the above steps, which are receiving receptive consideration by governments and business, fuel taxes, through their effects on prices, can nevertheless be used to affect demand and consumption. Depending on the responsiveness of gasoline demand to changes in price, these other policies could prove to be more or less attractive, depending on the circumstances. However, previous evidence does indicates that demand reductions from price (and tax) increases will likely not be large. On the other hand, different household groups, and households resident in different regions, would possibly be affected differentially. Evidence on these differences was provided by Greening, Jeng, Formby and Cheng (1995) and Puller and Greening (1999), using United States Consumer Expenditure Survey (CEX) data. These authors used a similar modelling approach to Archibald and Gillingham (1980a,b), which viewed the demand for gasoline as a derived demand for an input to a household production model of transportation services.

Other studies often estimate single demand equations for gasoline. Notwithstanding the wide array of data and models which have been used to study this problem, Espey (1996, 1998) finds that results are broadly similar in terms of estimated elasticities. That is, vehicle ownership variables do appear to significantly influence results, but otherwise there are small differences in estimates, whether models are estimated with cross-sectional or time-series data, or as static or dynamic relationships. It also appears that demand responsiveness in the United States to changes in prices and income are typically smaller than the responsiveness seen in other countries.

In this paper, rather than single-equation estimation of gasoline demand, such demand is modelled as one equation of a multi-equation demand system. Also, the influences of several other effects which the literature has found to be important determinants of demand are included. That is, the effect of household labour force participation, housing tenure status, household size and a variety of other household characteristics are taken into account. Several different household types in Canada and the United States are the basis for this study, employing Canadian Family Expenditure (FAMEX) Surveys, and United States CEX Surveys.

It is found that one does observe differences in elasticities between Canada and the United States, but these differences are not systematic by household type. That is, while elasticities might change in the same direction as family size for one household type in one country, this is not observed in the other country. In addition, it is seen that family size and housing tenure status variables have bigger effects on elasticities than region of residence, although elasticities are generally higher in Canada than in the United States. With only one exception, gasoline is found to be own-price and income inelastic. In the case of one Canadian household type, income *elastic* demand for gasoline is consistently observed in all regions of Canada.

The implications of the foregoing results are that, while one might not consider it to be particularly important to construct policies designed to yield differential effects across regions, care ought to be taken with respect to differential impacts on households with otherwise different characteristics. For example, households with certain characteristics have low income levels (renter households with more than one child). Thus a policy which places a heavy burden on these groups should probably be avoided, in the interests of equity.

In the remainder of the paper, Section 2 deals with the model specification and the computation of elasticities, and their standard errors. Section 3 discusses the data sources and household types. Section 4 briefly discusses the demand model estimation approach, and presents estimated elasticities for various household types and regions in Canada and the United States. Section 5 summarises and concludes.

2 Model Specification

In a recent paper, Nicol (2001) proposed a model of household demand which incorporated several aspects which have been found to be important determinants of consumer behaviour. These features had not all been simultaneously included in a general demand model. Households were first stratified by family size and housing tenure status (an approach suggested in research by Barnes and Gillingham, 1984, and Nicol, 1989). Then, the demand functions were specified to have a rank three form, resulting in share equations quadratic in real expenditures. Evidence of the appropriateness of this specification is given in Banks, Blundell and Lewbel (1997) and Lyssiotou, Pashardes and Stengos, (1999). Labour force participation effects have also been found to be important (Browning and Meghir, 1991, and Kaiser, 1993). Other effects included were age of adults in the household, tobacco consumption, vehicle ownership and a variable to condition on goods not included directly in the demand system. This last variable resulted in conditional demand functions for the equations directly included in the demand system, and avoids the otherwise implicit assumption of excluded goods being separable from those goods included directly in the system.

To make these ideas more explicit, suppose "goods" over which consumers make spending decisions are partitioned into three types. These are: goods of direct interest, denoted q (with their prices, p); labour force variables, ℓ (with their prices, r); and other goods of indirect interest, c (with their prices, p_c). For notational convenience, let $P = [p, r, p_c]$ and $Q = [q, \ell, c]$. Also, let z denote a vector of demographic or household characteristics variables.

Following the approach in Nicol (2001), a cost function conditional on z, ℓ and c can be defined. This conditional cost function is denoted as $C[p, u; \ell, c, z] = \min_q [p \cdot q | U(q; \ell, c, z) = u]$. The properties of such functions are discussed in Pollak (1969) and Browning (1983). The conditional, compensated demand functions, q_i are the derivatives of $C[p, u; \ell, c, z]$ with respect to p_i and can be denoted $q_i = f_i[p, u; \ell, c, z]$, $i = 1, \ldots, n$. Also, let y denote total expenditure on the n goods, $q = [q_1, \ldots, q_n]$. Note that n does *not* include goods which comprise expenditures on goods in the vector, c, and nor does y. Given this *conditional cost function*, a variation of the Quadratic Almost Ideal (QAI) demand system (Banks, Blundell and Lewbel, 1992 and 1997 and Fry and Pashardes, 1992) can be specified as follows

$$\ln C[p, u; \ell, c, z] = a(p; \ell, c, z) + \frac{b(p; \ell, c, z)}{[f(u) - g(p; \ell, c, z)]}, \tag{1}$$

which has the associated budget-share system

$$w_i = a_i'(p; \ell, c, z) + \frac{b_i'(p; \ell, c, z)}{b(p; \ell, c, z)}\{\ln(y) - a[p; \ell, c, z]\} + \frac{g_i'(p; \ell, c, z)}{g(p; \ell, c, z)}\{\ln(y) - a[p; \ell, c, z]\}^2 \tag{2}$$

where $a_i'(p; \ell, c, z), b_i'(p; \ell, c, z)$ and $g_i'(p; \ell, c, z)$ are the derivatives of $a(p; \ell, c, z), b(p; \ell, c, z)$ and $g(p; \ell, c, z)$ with respect to $\ln p_i$. Empirical implementation of (2) is achieved by specification of $a(p; \ell, c, z)$, $b(p; \ell, c, z)$ and $g(p; \ell, c, z)$ as follows,

$$a(p; \ell, c, z) = \alpha_0 + \sum_{i=1}^{n} \alpha_i(\ell, c, z) \ln p_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j \tag{3}$$

$$b(p;\ell,c,z) = \beta_0 \prod_{i=1}^{n} p_i^{\beta_i(\ell,c,z)} \tag{4}$$

$$g(p;\ell,c,z) = b(p;\ell,c,z) \cdot \lambda(p;\ell,c,z), \qquad \text{and} \tag{5}$$

$$\lambda(p;\ell,c,z) = \lambda_0 + \sum_i \lambda_i(\ell,c,z) \ln p_i \tag{6}$$

Linearisation of $\alpha_i(\ell,c,z), \beta_i(\ell,c,z)$ and $\lambda_i(\ell,c,z)$ complete the specification,

$$\alpha_i(\ell,c,z) = \sum_{j=1}^{n} \sum_{k=1}^{K} [\alpha_{jk}\nu_k] \tag{7}$$

$$\beta_i(\ell,c,z) = \sum_{j=1}^{n} \sum_{k=1}^{K} [\beta_{j0} + \beta_{jk}\nu_k] \tag{8}$$

$$\lambda_i(\ell,g,z) = \lambda_i \tag{9}$$

where the vector $\nu = [\nu_1, \ldots, \nu_K]^T$ is used to represent ℓ, c and z, for notational convenience. The parameterisations, (3)–(9), yield a budget-share system:

$$\begin{aligned} w_i \;=\; & \sum_{k=1}^{K} \alpha_{ik}\nu_k + \sum_{j=}^{n} \gamma_{ij} \ln p_j + [\beta_{i0} + \sum_{k=1}^{K} \beta_{ik}\nu_k][\ln(y) - a(p,\nu)] + \\ & \{\lambda_i + [\beta_{i0} + \sum_{k=1}^{K} \beta_{ik}\nu_k][\lambda_0 + \sum_{j=1}^{n} \lambda_j \ln p_j]\}[\ln(y) - a(p,\nu)]^2 + \mu_i \end{aligned} \tag{10}$$

Where μ_i, denotes a stochastic disturbance such that $[\mu_1, \ldots, \mu_n]^T \sim \mathrm{N}(0, \Omega)$. The covariance matrix of μ is singular, so only $n-1$ equations of the system need to be estimated, the parameters of the n'th being recoverable by the adding-up and integrability conditions indicated below. Empirical considerations relating to this stochastic specification will be discussed in Section 4.

Integrability conditions which the parameters of (10) must satisfy in order to be consistent with the conditional cost function, (1), are: $\sum_i^n \alpha_{i1} = 1, \sum_i^n \alpha_{ik} = 0, k = 2, \ldots K, \sum_i^n \gamma_{ij} = 0, \sum_i^n \beta_{ik} = 0$ all k, and $\sum_i^n \lambda_i = 0$, to satisfy adding up; $\sum_j^n \gamma_{ij} = 0$ to satisfy homogeneity; and $\gamma_{ij} = \gamma_{ji}, \forall i \neq j$, to satisfy symmetry of substitution effects. A negativity condition is also required of the Slutsky matrix of the model, but this cannot be satisfied globally for this class of system. In the empirical application which follows, the integrability conditions are imposed (apart from negativity), since earlier work indicated that homogeneity and symmetry restrictions could not be rejected for these data (Nicol, 1995a,b). With respect to negative semi-definiteness of the Slutsky matrix, this condition was satisfied at the point of sample means for the models estimated for different household groups. This condition cannot be imposed globally in systems such as the one estimated here. However, a high proportion of households exhibited negative Slutsky elasticities, indicating that the demand system is well-behaved for a large number of households.

This model parameterisation yields income (η_i), compensated price (ϵ^*_{ij}) and uncompensated price elasticities (ϵ_{ij}) respectively as follows (following Fry and Pashardes, 1992)

$$\eta_i = \{\beta_0 + \sum_k^K \beta_{ik}\nu_k + 2[\lambda_i + (\beta_0 + \sum_k^K \beta_{ik}\nu_k) \cdot \lambda_0](\ln(y) - \alpha_0)\}/w_i + 1 \tag{11}$$

$$\epsilon^*_{ij} = [1/w_i][\gamma_{ij} + (\beta_0 + \sum_k^K \beta_{ik}\nu_k)\lambda_j(\ln(y) - \alpha_0)^2 + w_i(\eta_i - 1)(w_j - \sum_k^K \alpha_{jk}\nu_k)] + w_j - \delta_{ij} \tag{12}$$

$$\epsilon_{ij} = \epsilon^*_{ij} - w_j\eta_i \tag{13}$$

where $\delta_{ij} = 1$ if $i = j$ and 0 otherwise. It should be noted that these elasticity formulae take into account evaluation at normalised prices, $p = [1, \ldots, 1]$ and $y = 1$, which are zero when logs of p_i and y are taken, and that evaluation further requires a value for the vector ν. The vector of sample means of all households, or groups of households, can be used for this purpose.

Standard errors for these elasticities are computed using approximation methods. Thus if $h[\hat{\theta}]$ is a vector of elasticities, with its elements nonlinear in $\hat{\theta}$ ($\hat{\theta}$ being the vector of parameter estimates from (10)), a variance covariance estimator, $\hat{\mathrm{V}}[h(\hat{\theta})]$, can be estimated as follows

$$\hat{\mathrm{V}}[h(\hat{\theta})] = H[\hat{\theta}]\{\hat{\mathrm{V}}[\hat{\theta}]\}H[\hat{\theta}]^T \tag{14}$$

where $H[\hat{\theta}]$ is the matrix of derivatives of the elements of $h[\hat{\theta}]$ with respect to the elements of $\hat{\theta}$, and $\hat{\mathrm{V}}[\hat{\theta}]$ is a consistent estimator of the variance-covariance estimator of $\mathrm{V}[\hat{\theta}]$.

3 Data

3.1 FAMEX Data and Prices

The Canadian expenditure data for this study were drawn from the 1969, 1974, 1978, 1982, 1984, 1986, 1990 and 1992 FAMEX survey public-use microdata files. Expenditures in these Surveys are reported for a calendar year, on a recall basis. Six household types were extracted from the eight surveys. These types were classified by three family sizes: married couples without children (0); married couples with one child (1); and with two children (2). Also, two types of housing tenure were used to further classify households: home-owner households with mortgages (MOR); and home renter (REN) households. The six categories were thus defined as MOR0, MOR1, MOR2, REN0, REN1 and REN2 respectively. For all household types, only those with age of head 18–65 and no self-employed members were included in the samples.

Six expenditure categories were included in the demand models to be estimated. These were: food consumed at home (F), alcoholic beverages (A), clothing (C), gasoline (G), other automobile operation (O) and public transportation (P). All expenditures *excluded* from the "direct", six-equation demand system were dealt with as an aggregate conditioning goods, for each of the six households' demand systems. Labour force participation status of the male and female household members were included as explanatory (dummy) variables. These labour force participation variables interacted with other variables on the right hand side of the estimating equations. Additional household characteristics variables included as explanatory variables were age of head of household, tobacco consumption, immigration status and vehicle ownership. These last three variables were zero-one dummy variables.

Price data were taken from the Statistics Canada publication *Consumer Prices and Price Indexes*, Catalogue No. 62-010. These data reflect regional differences in prices in Canada for a variety of goods at a point in time. The prices were rebased to 1978, and normalised to unity at their mean. Further details of the price data, some of which had to be aggregated from less regionally aggregated data, are available from the author on request.

3.2 CEX Data and Prices

The CEX expenditure data were drawn from the 1980–81, 1982–83, and the annual, 1984–1992 Interview Survey Public-Use Tapes of the CEX for the United States. Since one reporting group within the CEX reports expenditures every month for the preceding quarter, monthly variation in price data can be used in identification of price parameters.

Again, family size and housing tenure were used to partition households in the same manner as for the FAMEX data referred to above. For the six household types, only those with age of head 18–65 and no self-employed members were included in the samples.

The expenditure categories based on the CEX data were chosen to be as close as possible to those used with the FAMEX data, referred to above, again yielding a comparable six-equation system with F, A, C, G, O and P as defined earlier.

Labour force participation effects were also included in the United States demand equations. The CEX data contain information on the labour force participation status of adult household members. Consequently, these effects were introduced as labour force participation dummy variables. One variable was included for each of the adult male and female household members. In addition, these dummy variables were interacted with various variables on the right hand side of the estimating equations. Finally, age of head, tobacco consumption, and vehicle ownership variables were again included, as was a variable reflecting expenditures on goods not included directly in the system.

The price data used in this part of the study are unique, and were compiled by the author specifically for this and related projects. In brief, the United States Consumer Price Index data were used for many cities and States in the United States. These data only reflect inter-temporal price variation. To incorporate a regional dimension to price effects, American Chamber of Commerce Research Association (ACCRA) data were used, in conjunction with United States CPI data. Further details of these data are in Nicol (2001), and more detailed information is available from the author on request. Also, a longer more detailed version of Nicol (2001) is available as Nicol (1998) at

http://people.uleth.ca/~nicolc/papers/RankUS/July_98

4 Demand System Estimation and Elasticity Results

4.1 Exogeneity of Explanatory Variables

It is clear that several of the variables included in the demand model discussed in Section 2, such as tobacco consumption and vehicle ownership, are jointly determined with expenditure shares. In addition, purchase infrequency for some expenditure categories during a quarter (for CEX data) calls into question the exogeneity of total expenditures (y). The inclusion of labour force participation effects also indicates possible endogeneity.

In all systems estimated total expenditures, labour force participation of adult male and female household members, other expenditures $p_c \cdot c$, vehicle ownership and tobacco consumption were included as right-hand side variables, but were accounted for through the use of instrumental variables. Other right-hand side variables which were included but did not require instruments were age of the head of the household, and prices.

In these circumstances, the additional instrumental variables required to implement estimation were: age squared of adult male and female household members; regional dummy variables; linearly independent squares and cross-products of price variables; a time trend; income after taxes and its square; income after taxes interacted with all adult age variables; personal taxes; government transfer payments; seven occupation dummy variables each for male and female adult members; and seven education dummy variables each for male and female adult members.

Given the above set of instrumental variables, estimation of (10) was carried out for all of the household groups and expenditure category demand systems indicated earlier. The GMM procedures in TSP, Version 4.3 were employed, allowing for heteroskedasticity of unknown form in the computation of the estimated variance-covariance matrices of these systems, where possible. Sargan (1973) or J tests of over-identifying restrictions indicated non-rejection of the over-identifying restrictions.

4.2 Estimated Elasticities

Complete matrices of compensated and uncompensated price elasticities and income elasticities for all goods and household types were computed based on the formulae, (11)–(13). Since the focus of this study is gasoline own-price and income elasticities, only these are presented. Complete matrices of elasticities for all goods are available from the author on request, or can be found in Nicol (1998), at the URL indicated above.

As stated earlier, elasticities are evaluated relative to particular household groups (MOR0–REN2), for either Canada or the United States. In addition, while elasticities can be based on averages of budget-shares and other relevant variables of all households of a particular type, the elasticities can also be computed based on averages of the same variables, but for households living in specific regions of either country.

The Canadian FAMEX data permit classification of households resident in five regions of Canada: Atlantic Provinces (1), Québec (2), Ontario (3), Prairie Provinces (4) and British Columbia (5). For United States CEX data, households are defined as residing in one of four regions: North-east (1), Mid-west (2), South (3) and West (4). In Tables 1 and 2, own-price and income elasticities for household groups MOR0–REN2 are presented for the five regions of Canada, and the four regions of the United States respectively.

Table 1 indicates that households in Canada with one child, whether home owner or renter, exhibit weaker responses to own-price changes in their demand for gasoline than households of other sizes. The standard errors of the elasticities are beneath the elasticity estimates. This weaker responsiveness is comprehensive across regions. In addition, while responsiveness is greater for either household type with no children or two children, responsiveness of renters is *ceteris paribus*, higher than for home owners.

On the other hand, with respect to income elasticities, the *reverse* pattern is observed for single child households in Table 1. That is, single-child households have greater income elasticities of demand than childless or two-child households. Again, childless households' elasticities are lower than the elasticities of households with two children. Only in the case of MOR1 households, however, are elasticities greater than unity observed.

Turning to the estimates in Table 2 for United States households, the first thing one notes is the poorer precision with which own-price elasticities are estimated. Of a total of twenty-four regional estimates, five have *positive* values, although their standard errors are sufficiently large as to indicate this is not necessarily problematic.

In contrast with the results in Table 1, it is households in MOR1 and REN1 groups which exhibit *greater* responsiveness of demand to own-price changes. This is true irrespective of region. Furthermore, with the exception of these two groups, it is observed that Canadian households' gasoline demand is more responsive to own-price changes than United States households. This is consistent with earlier research in general, but it is of interest to note that one does observe greater responsiveness for the MOR1 and REN1 household groups in the United States. This tends to reinforce the notion that it is important to look beyond average elasticities for all households, since households of different types can and do respond differently, even in different countries. Again, however, it is evident that regional differences in elasticities are smaller than differences associated with the family size and the housing tenure household characteristics.

A consideration of income elasticities for the United States indicates that households with no children within MOR or REN tenure groups have the lowest elasticities. This is not quite in line with the Canadian results, where MOR0/MOR2 and REN0/REN2 estimates were fairly close, with MOR1 and REN1 being substantially different from the other two household sizes' elasticities. However, elasticities by household type are not always higher in Canada than in the United States. In addition, income elasticity variation across regions in the United States is smaller than variation across household size or housing tenure status.

To summarise, the elasticities obtained based on estimation of gasoline demand as one equation in a system of demand equations are consistent with results obtained in earlier research. It is generally the case that gasoline demand is own-price and income inelastic for both countries. There is, however, variation in elasticities across regions, although the degree of variation is greater with respect to the family size and housing tenure status variables. Only one household type of the six considered exhibits gasoline demand which is income elastic, and this is seen for Canadian households. Elasticities are generally higher in Canada than in the United States, which is again consistent with results reported in the literature, although this does not always hold for income elasticities of comparable households. An advantage of the approach in this paper is that elasticity estimates can be obtained for disaggregated household groups. Since the results indicate there can be substantial differences in these estimates depending on the characteristics considered, policy-makers will likely wish to use this finer level of detail if taxation or price-change policies are developed which are geared towards the modification of household gasoline consumption behaviour.

5 Summary and Conclusions

In this paper, a six-equation, rank three demand system was estimated for Canada and the United States, which included a gasoline demand equation. The model also controlled for the non-separability of labour force participation effects, non-separability of other goods not included directly in the demand system, and the influence of a variety of household characteristics effects.

The same model was estimated using Canadian and United States household microdata, for six different household groups, varying by family size and housing tenure status. The objective was to obtain gasoline demand elasticities for these different household groups, and to obtain estimates of these elasticities for different regions in the two countries.

While there have been many empirical studies which have estimated own-price and income elasticities of gasoline demand, this paper uses a demand system approach, unlike many other studies which estimate single gasoline demand equations, or a model based on household production of transportation services. It is rare that such models can identify separate elasticities for different household groups or regions, although Greening, Jeng, Formby and Cheng (1995) and Puller and Greening (1999) have done so for the United States, with the household production type of model.

It is found that gasoline demand is own-price inelastic, and income inelastic, except for one Canadian household type, which has income elastic demand for gasoline. Gasoline demand is generally more responsive to price and income changes in Canada, but this is not universally true for all household types. Also, while regional differences in elasticities are observed in both Canada and the United States, family size and housing tenure status have larger impacts on differences in elasticities across households.

Thus, while the elasticities obtained in this paper are consistent with earlier results, a unique opportunity is provided which allows for comparisons of elasticities by any household group one might select. This is a useful feature of the approach, since the impact of general policies designed to influence demand behaviour can have differential impacts on households with different characteristics. The outcome of these differential effects might not be desirable to a policy-maker. The existence of estimates of the extent to which responses to price and income changes differ is therefore a useful additional piece of information provided by this methodology.

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